National Renewable Energy Laboratory
USA Trough Initiative

Thermal Storage for Rankine Cycle and Combined Cycle Power Plants

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Thermal Storage for Parabolic Trough Power Plants

Study objectives:

- Investigate thermal storage options
- Identify, evaluate, and recommend concepts for Rankine cycle and integrated solar combined cycle plants
- Develop a conceptual design for an integrated plant with solar fractions up to 20 percent

Recommendations of Thermal Storage Evaluation

Near term

Hot and cold tank nitrate salt

Mid term

- Nitrate salt thermocline storage with taconite or limestone fill material
- Concrete

Long term

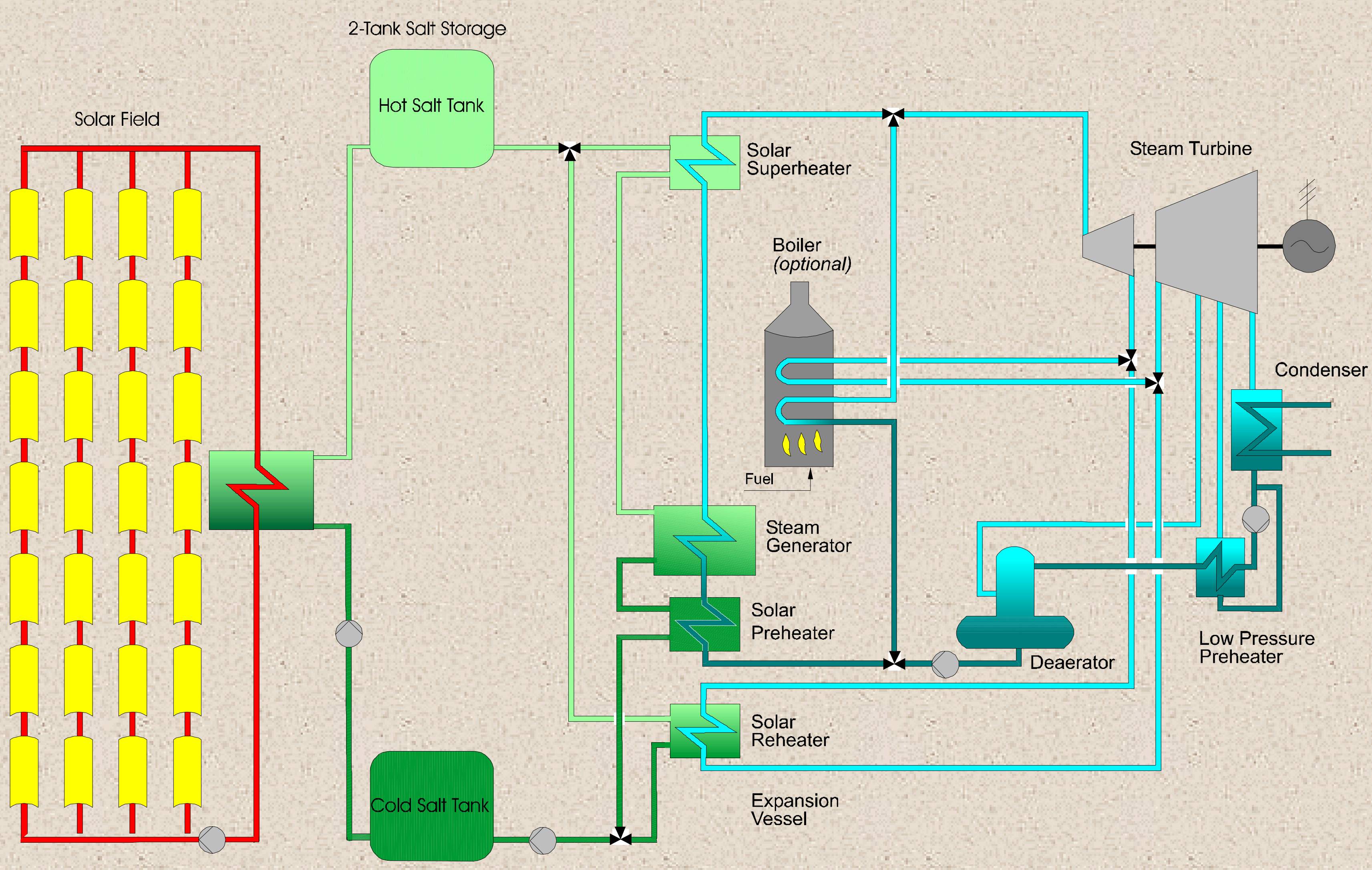
Cascaded phase change material
(R&D required, not investigated here)

Cost goal of $25/kWht

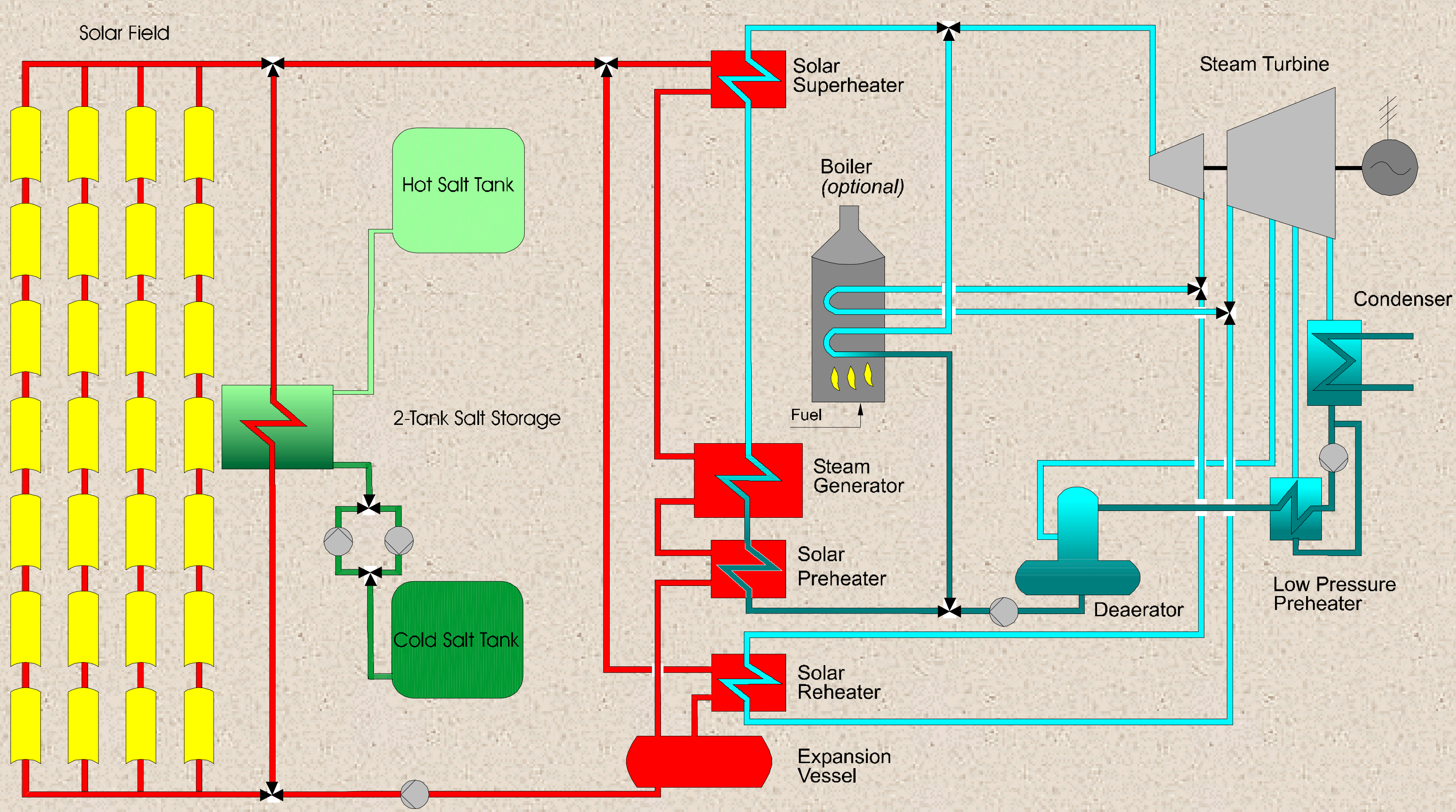
Preferred Near Term Approach

- Hot and cold nitrate salt tanks, charged by an oil-to-salt heat exchanger
- Tertiary nitrate salts offer favorable combination of low cost, low vapor pressure, high density, reasonable specific heat, reasonable melting temperature, and low chemical reactivity

Salt Steam Generator



Oil Steam Generator



Equipment Arrangement

- With salt steam generator, charge/discharge cycle imposes two heat exchanger approach temperatures; with oil steam generator, three
- Salt steam generator requires smaller heat exchangers; however, auxiliary energy demand for nitrate salt pumps is higher because all thermal energy must pass through oil-to-salt heat exchanger
- Project economics favor oil steam generator

Oil-to-Salt Heat Exchanger Design

- Tube rupture will expose organic heat transfer fluid to nitrate salt oxidant. Fluid will vaporize, and vapor will accumulate in thermal storage tank ullage volume
- Nitrate salt and gasoline reaction tests (at 1,100 ºF) by Sandia showed hydrocarbon vaporization and combustion in air, but no oxidation reactions with nitrate salt

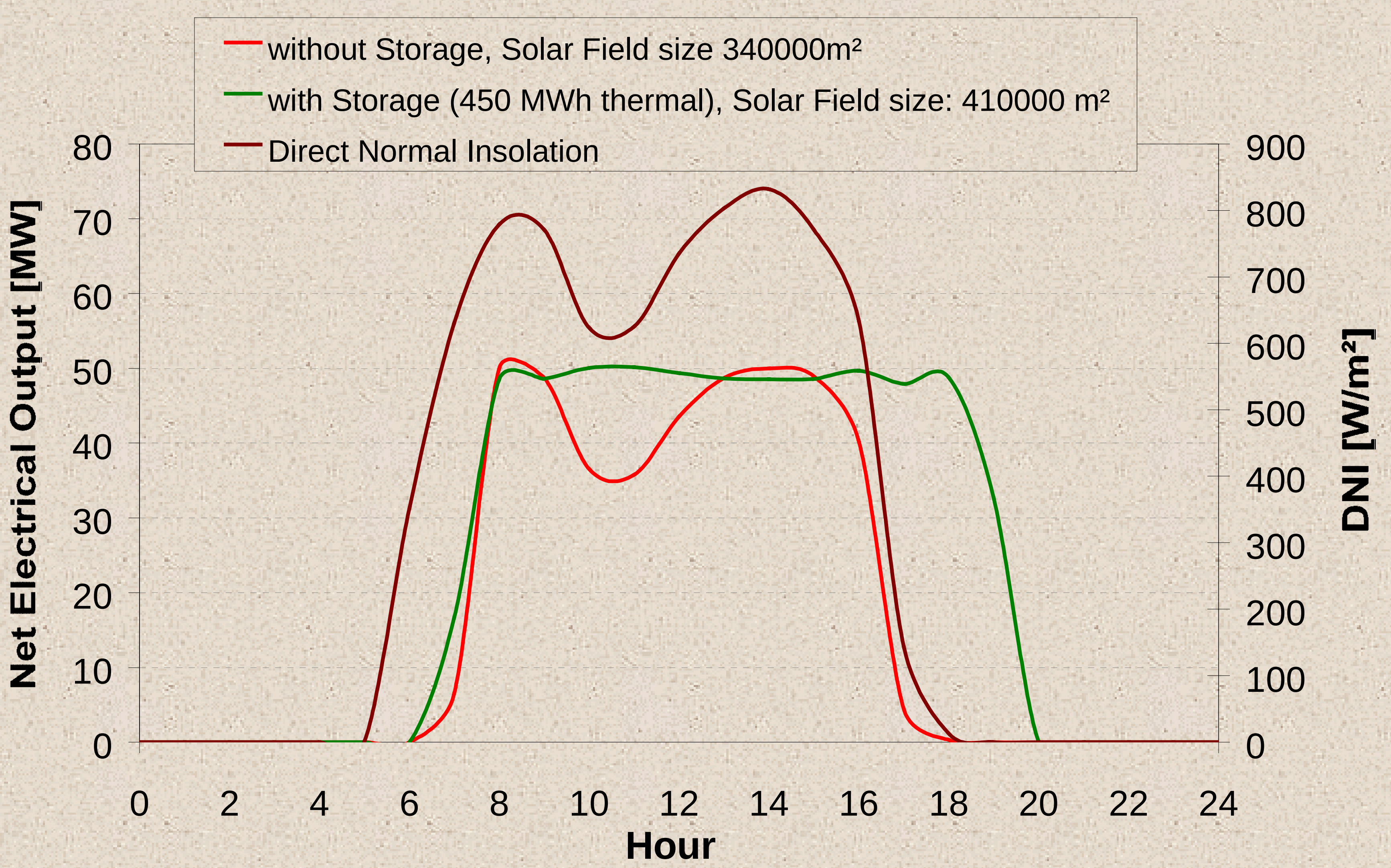
Oil-to-Salt Heat Exchanger Design

- Likelihood of combustion or explosion is small: Therminol VP-1 is at least 350 ºF below auto-ignition temperature, and Dow engineers do not expect nitrate salt decomposition/oxidation reaction
- Nitrate salts are stable in presence of nitrogen; permanent nitrogen ullage gas could be used in storage tanks
- Standard TEMA heat exchanger

Thermal Storage for Rankine Plants

- Two tank nitrate salt storage systems are viable for Rankine cycle plants
- Final feedwater temperature of 455 ºF, and main and reheat steam temperatures of 700 ºF, limits range of salt temperatures to about 130 ºF; however, nitrate salt and the oil-to-salt heat exchangers are inexpensive, and the technical risk should be low
- With a 3 hour system, the capacity factor increases from 25 to 31 percent, and the turbine operates for more hours at full load
- Unit storage costs of $27 to $32/kWht

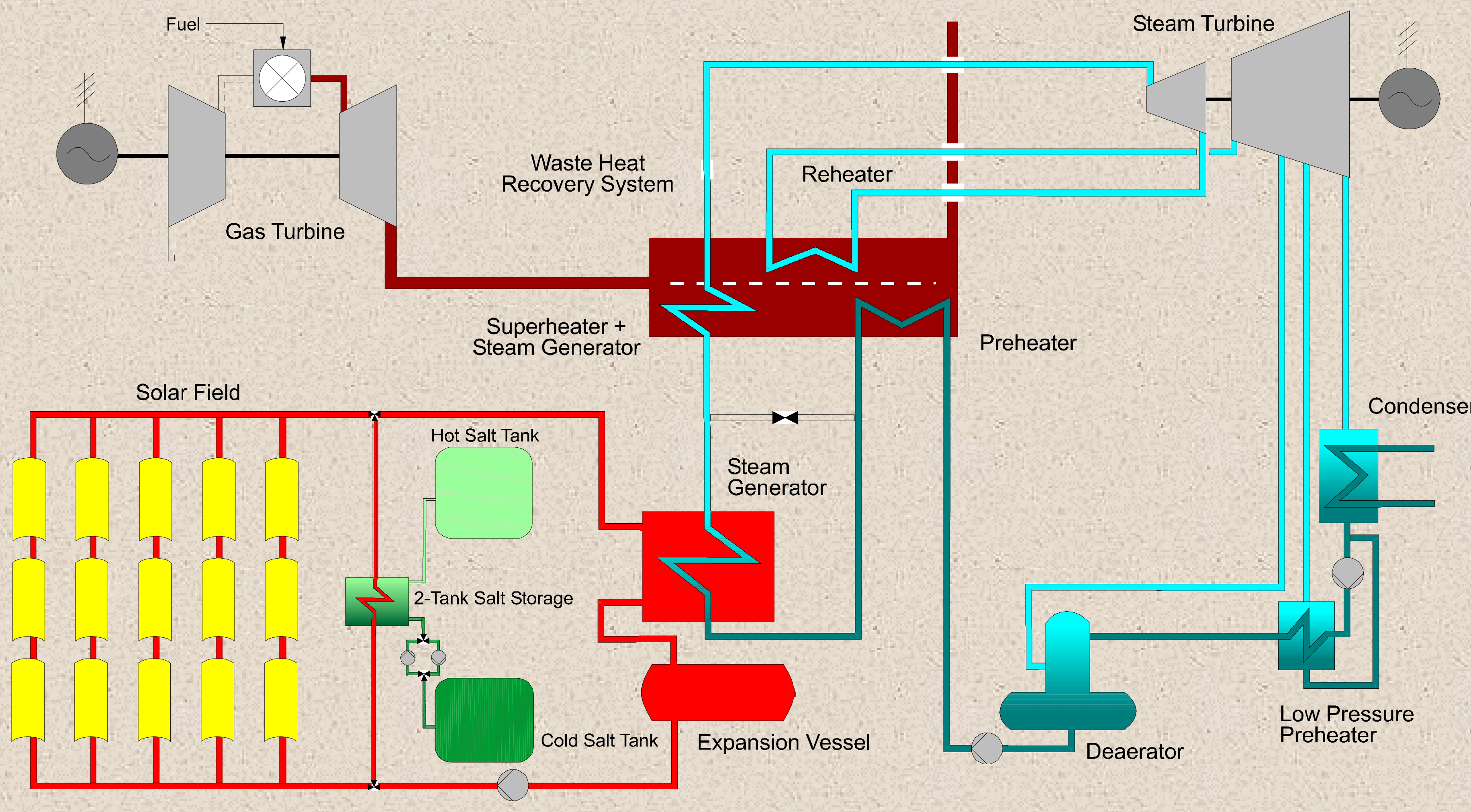
Summer Output of a 50 MWe Rankine Cycle Plant



Thermal Storage for Rankine Plants

- System economics may be improved by:
  - Allowing the main and reheat steam temperatures to decay to 690 ºF during storage discharge
  - Using a thermocline storage system, which substitutes low cost limestone for nitrate salt
  - Using concrete as the storage medium. Investment costs under $25/kWht are likely; however, long-term stability of concrete still has to be proven

Integrated Plant with Thermal Storage



Thermal Storage for Integrated Plants

- Highest solar conversion efficiencies occur with feedwater temperatures as high as possible

- Integrated plants with annual solar contributions of 2 to 4 percent are poor candidates for thermal storage

– Final feedwater temperatures are as high as 620 ºF

– Small difference between hot and cold salt tank temperatures leads to unit storage costs of $35 to $40/kWht

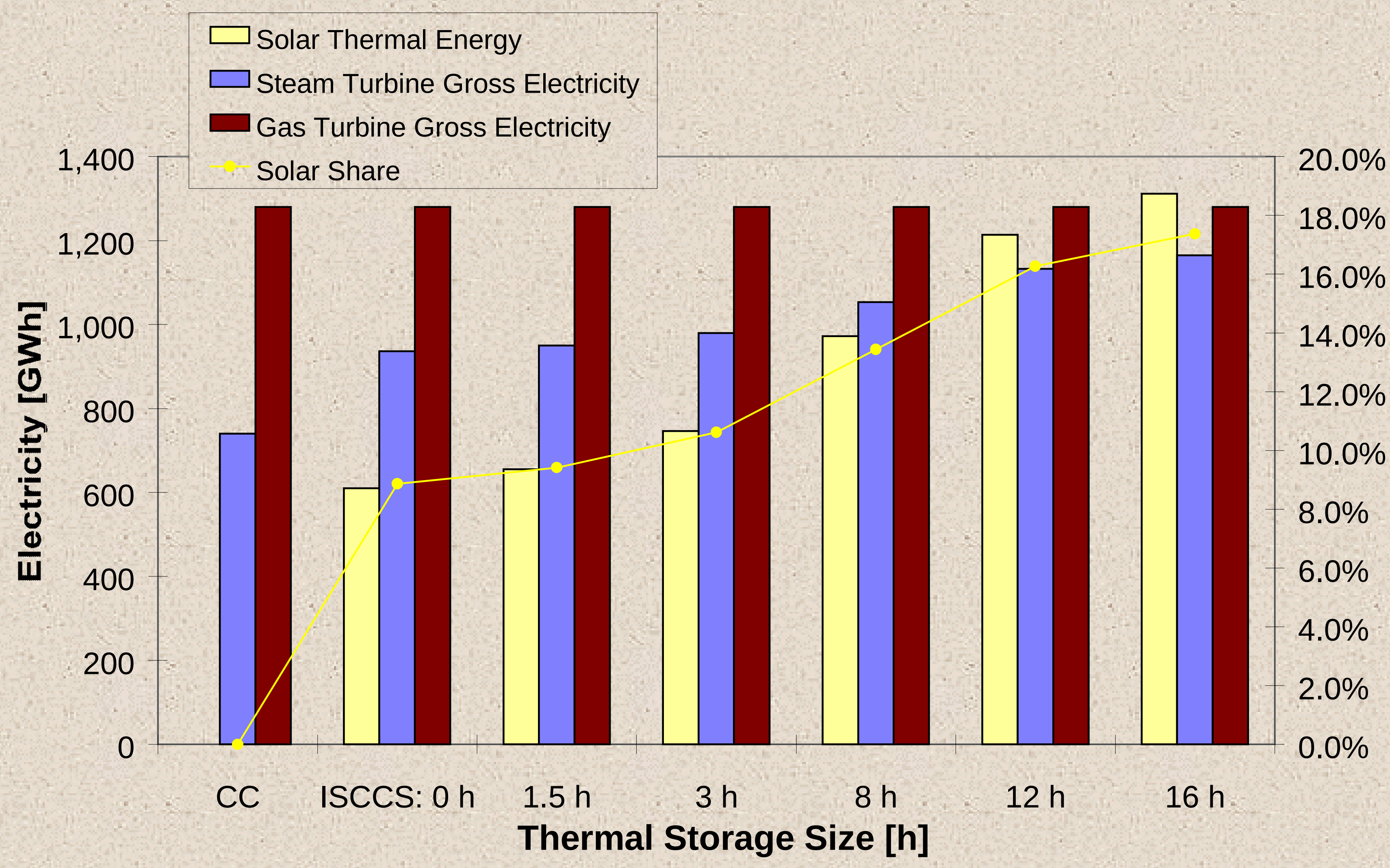
Thermal Storage for Integrated Plants

- Integrated plants with annual solar contributions of 8 to 10 percent are (thermodynamically) potential candidates for thermal storage

  – Main steam saturation temperatures are higher than SEGS plants; however, final feedwater temperatures are comparable, and superheated steam is not required

  – Unit storage costs are \$24 to \$30/kWht

Annual Performance of Integrated Plant with Storage



Conclusions

Thermal Storage for Rankine Cycle Plants

- Hot and cold tank nitrate salt concept is viable for Rankine cycle plants
- With unit storage costs of $25 to $32/kWht, adding thermal storage increases levelized energy cost slightly
- Technical risks are moderate, and thermal storage should be useful for sites which assign a value for energy dispatch

Conclusions

Thermal Storage for Integrated Plants

- With a 16 hour storage system, annual solar contributions up to 17 percent are feasible; net conversion efficiencies are in the range of 29 to 32 percent

- With storage unit costs about \$25/kWht, levelized energy costs are not affected markedly